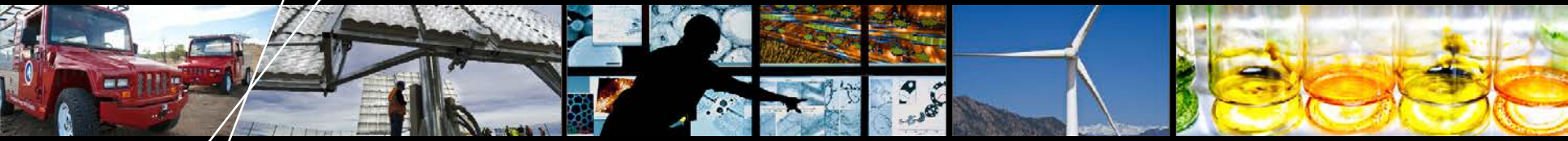
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Maximizing the Potential of Renewable Energy



Naval Postgraduate School Defense Energy Seminar Lecture Series

September 5, 2014

Dr. Dan E. Arvizu

Laboratory Director

Energy Market Dynamics

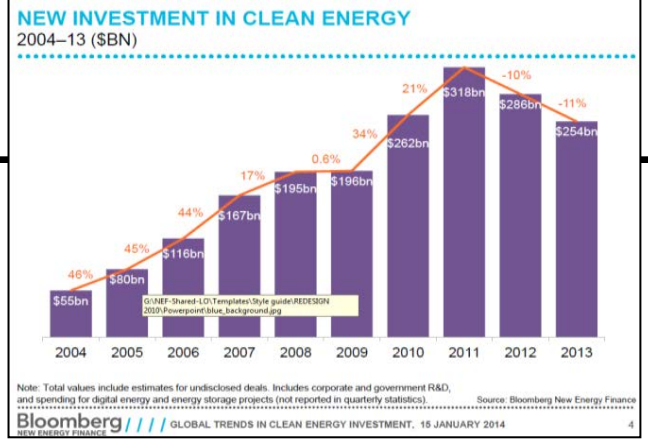
Global renewable industry growing, still faces challenges

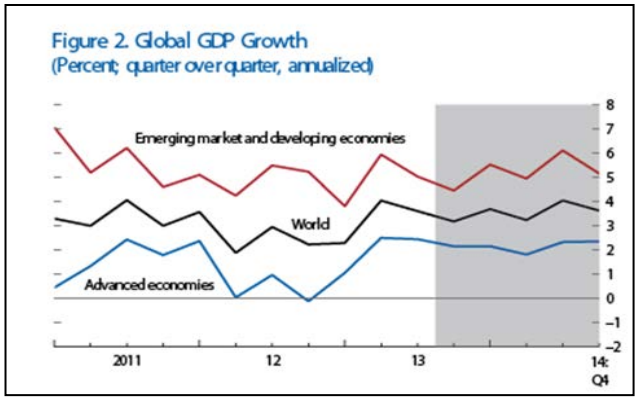
Public policy evolving

Effects of Great Recession still evident

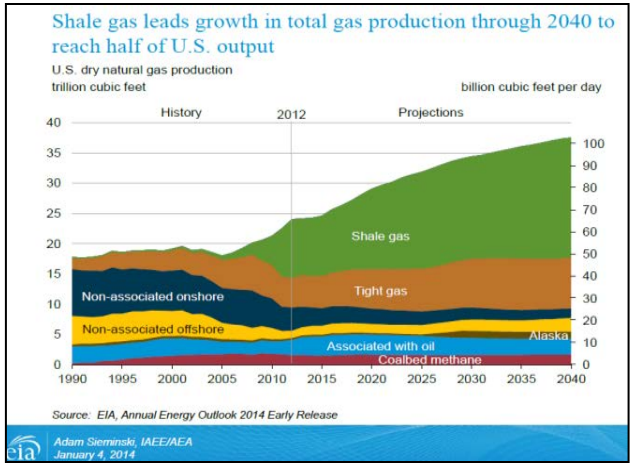
Shale gas a growing focus in U.S. and elsewhere

Infrastructure investments will be made, must focus on flexibility



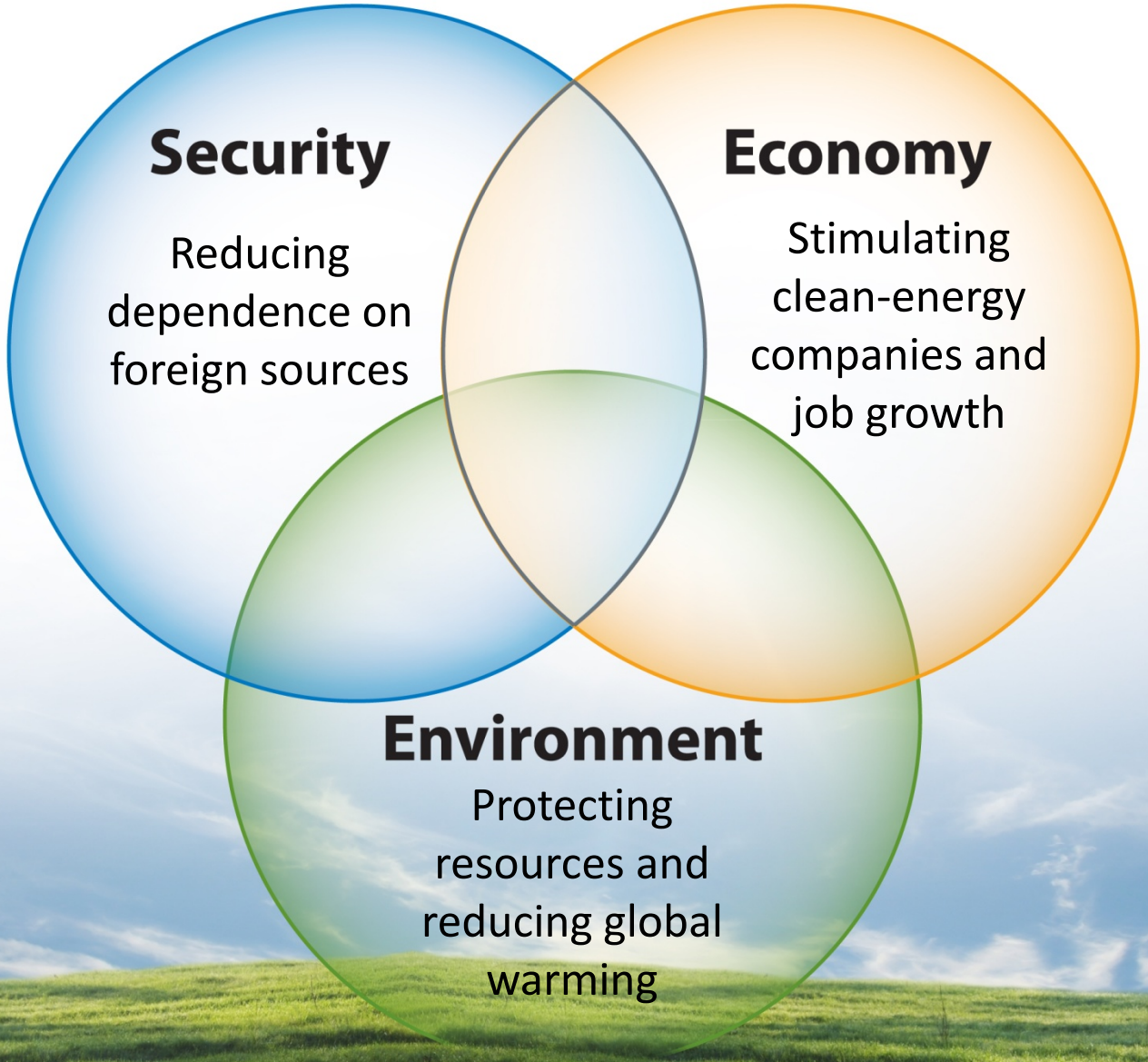


http://www.imf.org/external/pubs/ft/weo/2014/update/01/index.htm



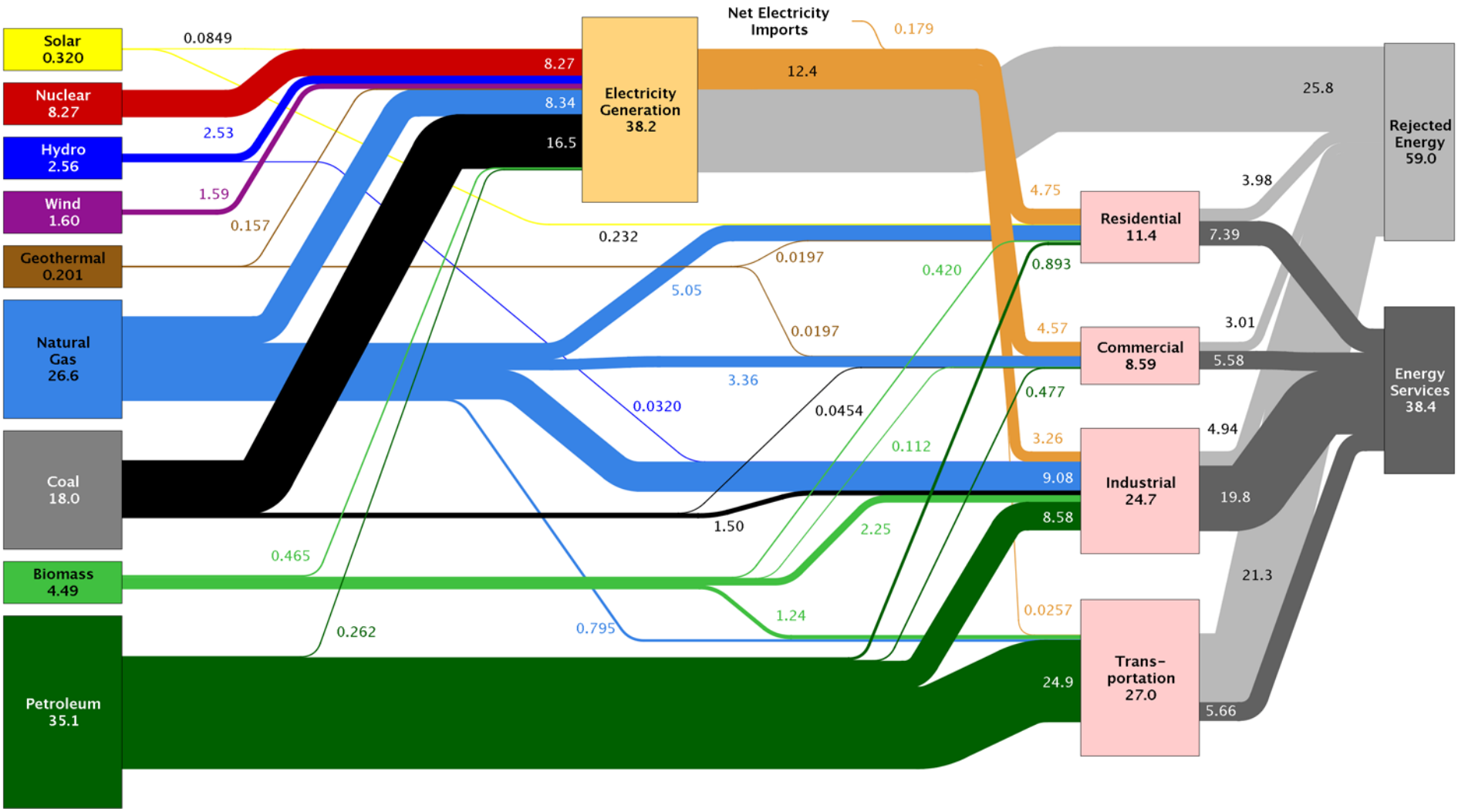
Rev 5/14/14

National Energy Imperatives



Estimated U.S. Energy Use in 2013: ~97.4 Quads

Lawrence Livermore National Laboratory



Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

A Profound Transformation is Required

Today's Unsustainable Energy System

Future Sustainable Energy System

TRANSFORMATION

- Limited fuel diversity
- Subject to price volatility
- Inefficient and rigid
- Significant carbon emissions
- Delivery systems vulnerable
- Aging infrastructure

- Diverse supply options
- Affordable, stable and reliable
- Efficient and flexible
- Carbon neutral
- Secure and resilient
- Engine for innovation

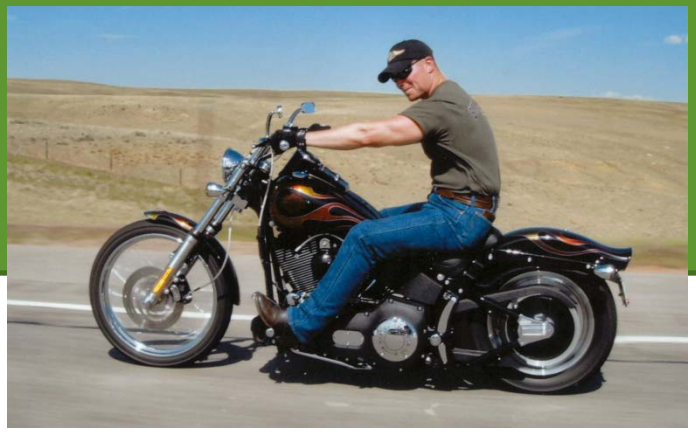
1/13/2014

Change is Hard

"Facts are important but not sufficient to change human behavior."

—Dr. Arthur Caplan, Bioethicist

2014 National Science Board Award Winner for Public Service



Smoking causes cancer.

Riding without a helmet is dangerous.

Vaccinations prevent disease and death.

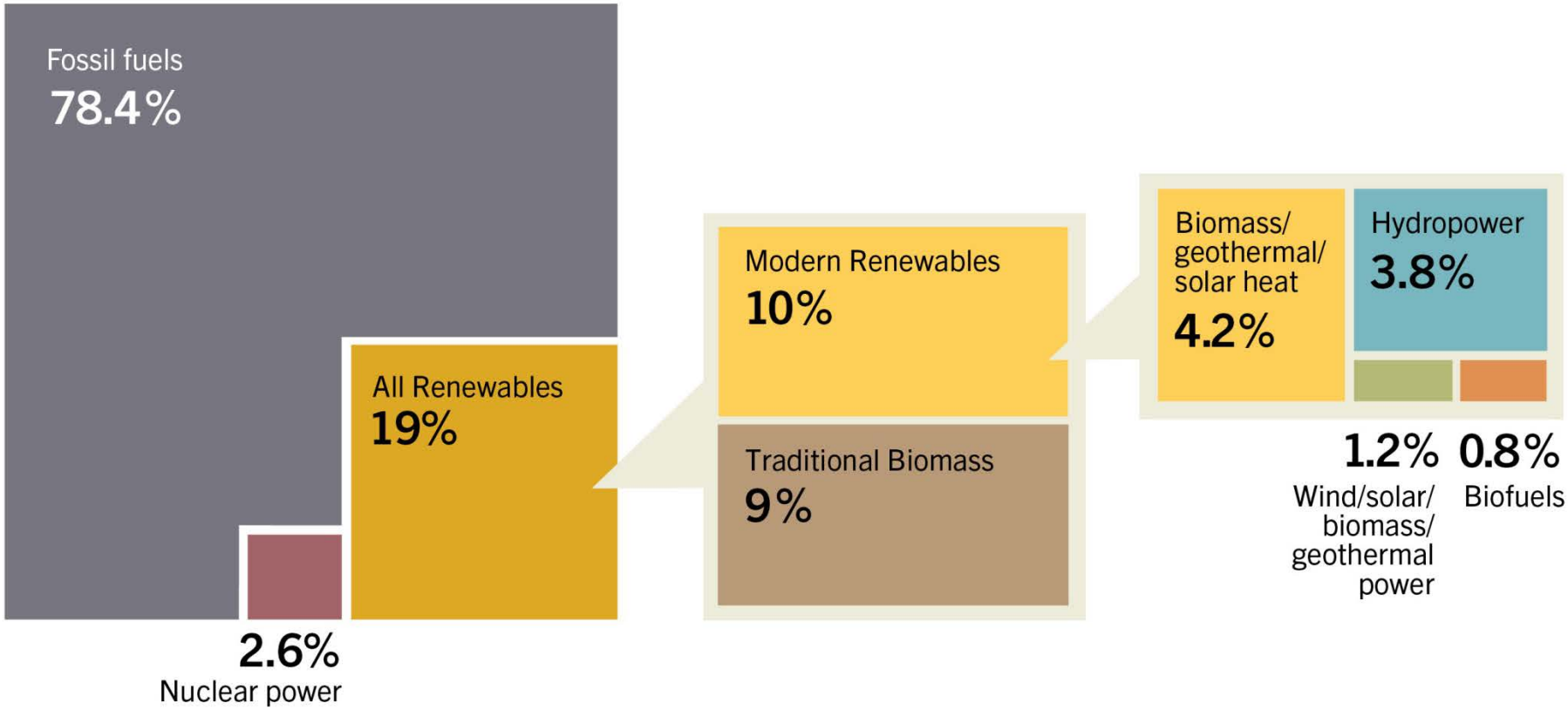
Transition to a Sustainable Energy Economy

What will compel a transition?

Addressing the three myths….

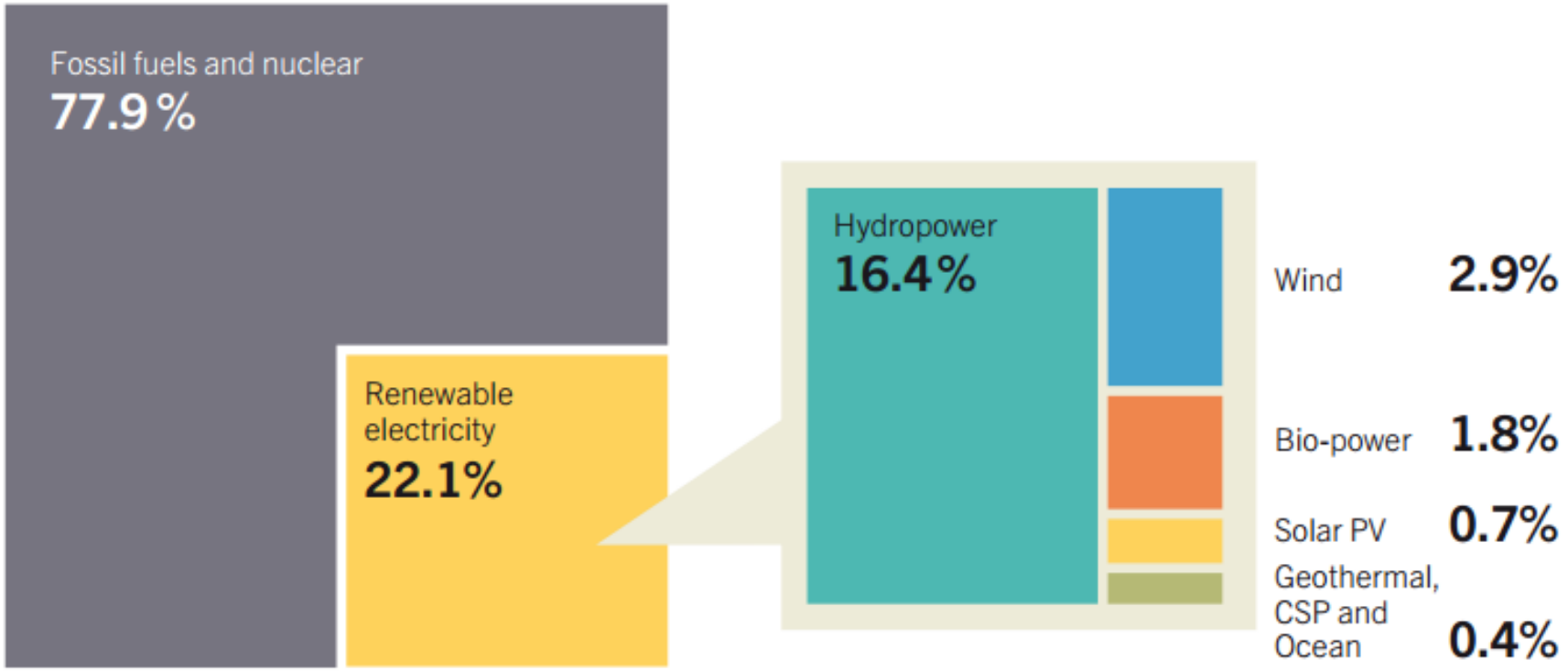
- **You don't have to go without.** ***No sacrifice required.***
- **You can still have choice.** ***Choices are enhanced.***
- **Pace matters; there are consequences for not acting now.** ***Security, cost and competitiveness, and environmental quality.***

Estimated Renewable Energy Share of Global Final Energy Consumption (year end 2012)



Source: *REN21 Global Status Report 2014*
http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf

Estimated Renewable Energy Share of Global Electricity Production (year end 2013)



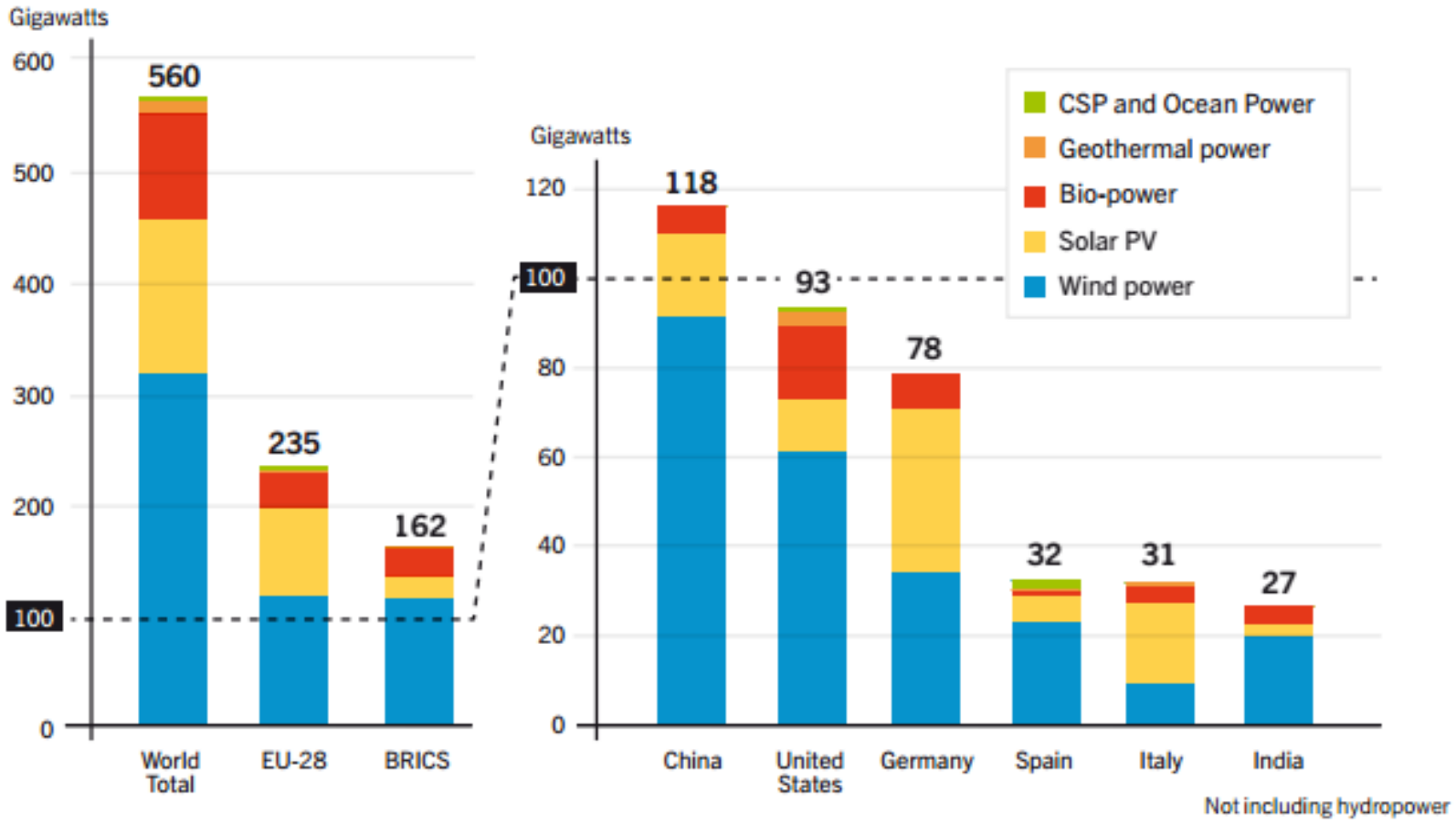
Based on renewable generating capacity in operation end-2013. Data do not add up due to rounding.

i - The GSR 2013 reported a global total of 990 GW of hydropower capacity at the end of 2012; this figure has been revised downward due to better data availability. This adjustment also affects the global figure for total renewable power capacity. In addition, global hydropower data and thus total renewable energy statistics in this report reflect an effort to remove capacity of pure pumped storage from the totals. For more information, see Methodological Notes, page 142.

Source: *REN21 Global Status Report 2014*
http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf

Worldwide Renewable Power Capacity

Figure 4. Renewable Power Capacities in World, EU-28, BRICS, and Top Six Countries, 2013

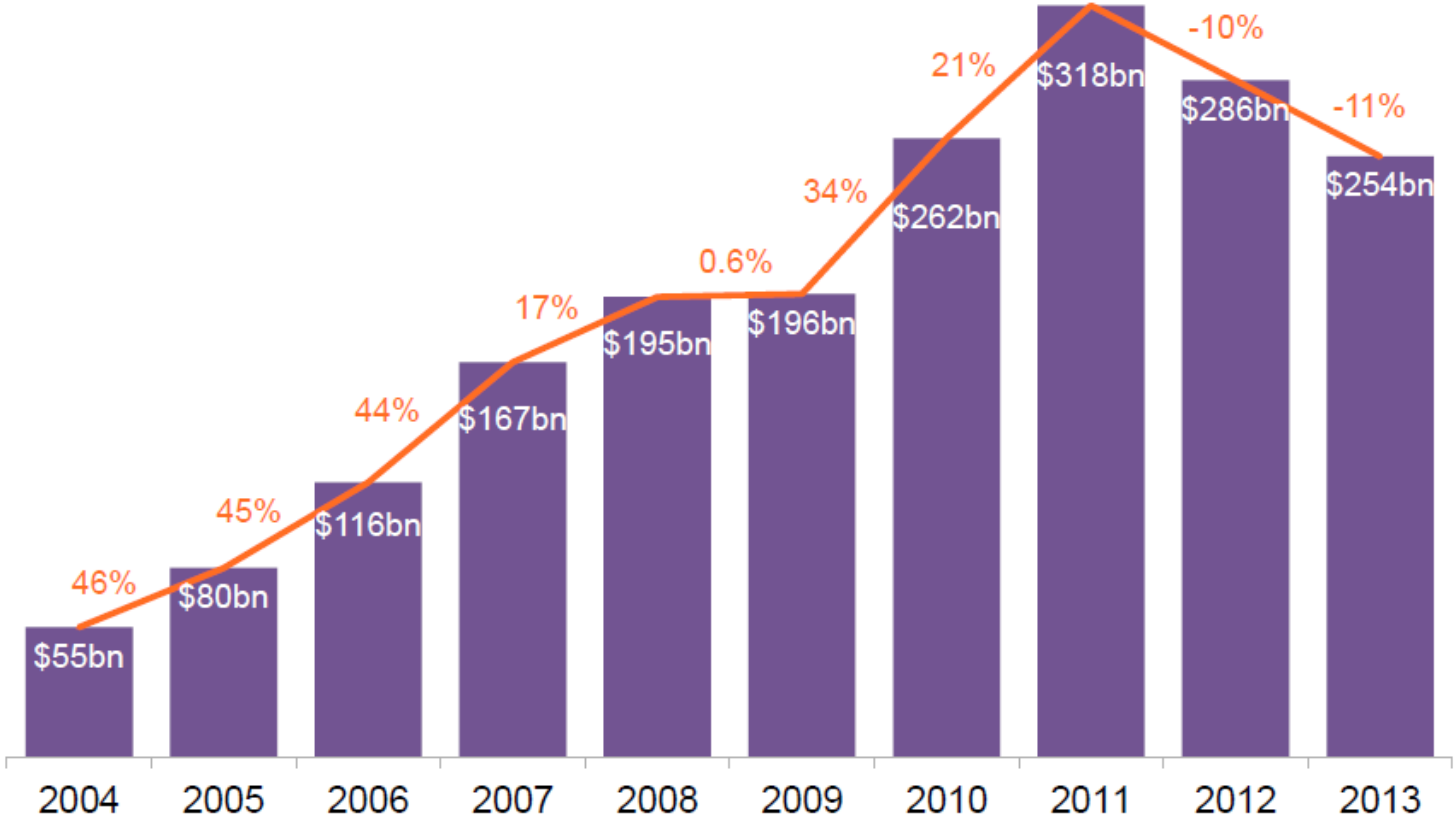


Source REN21 ***Renewables 2014 Status Report***
http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf

Global New Investment in Renewables

NEW INVESTMENT IN CLEAN ENERGY

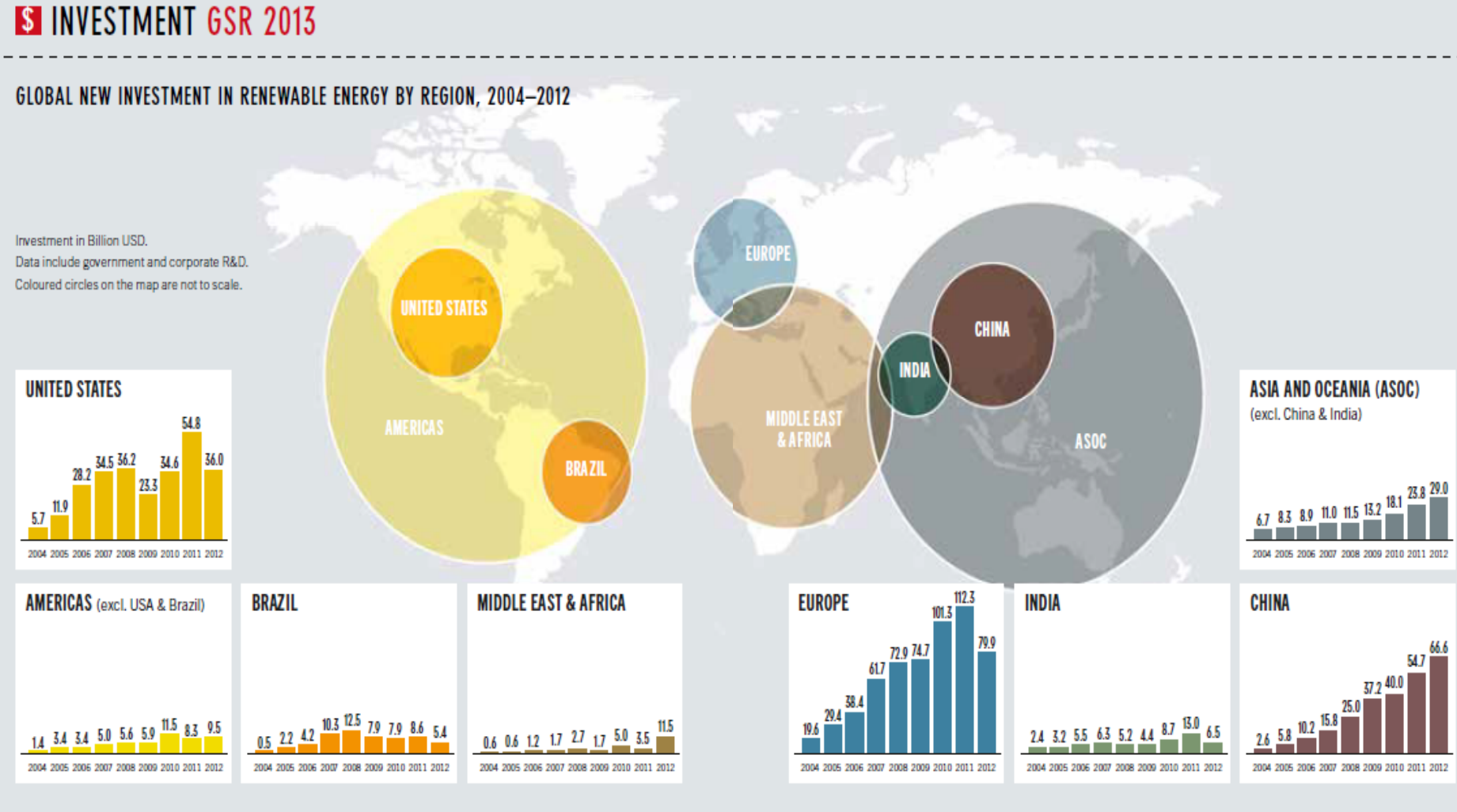
2004–13 ($BN)



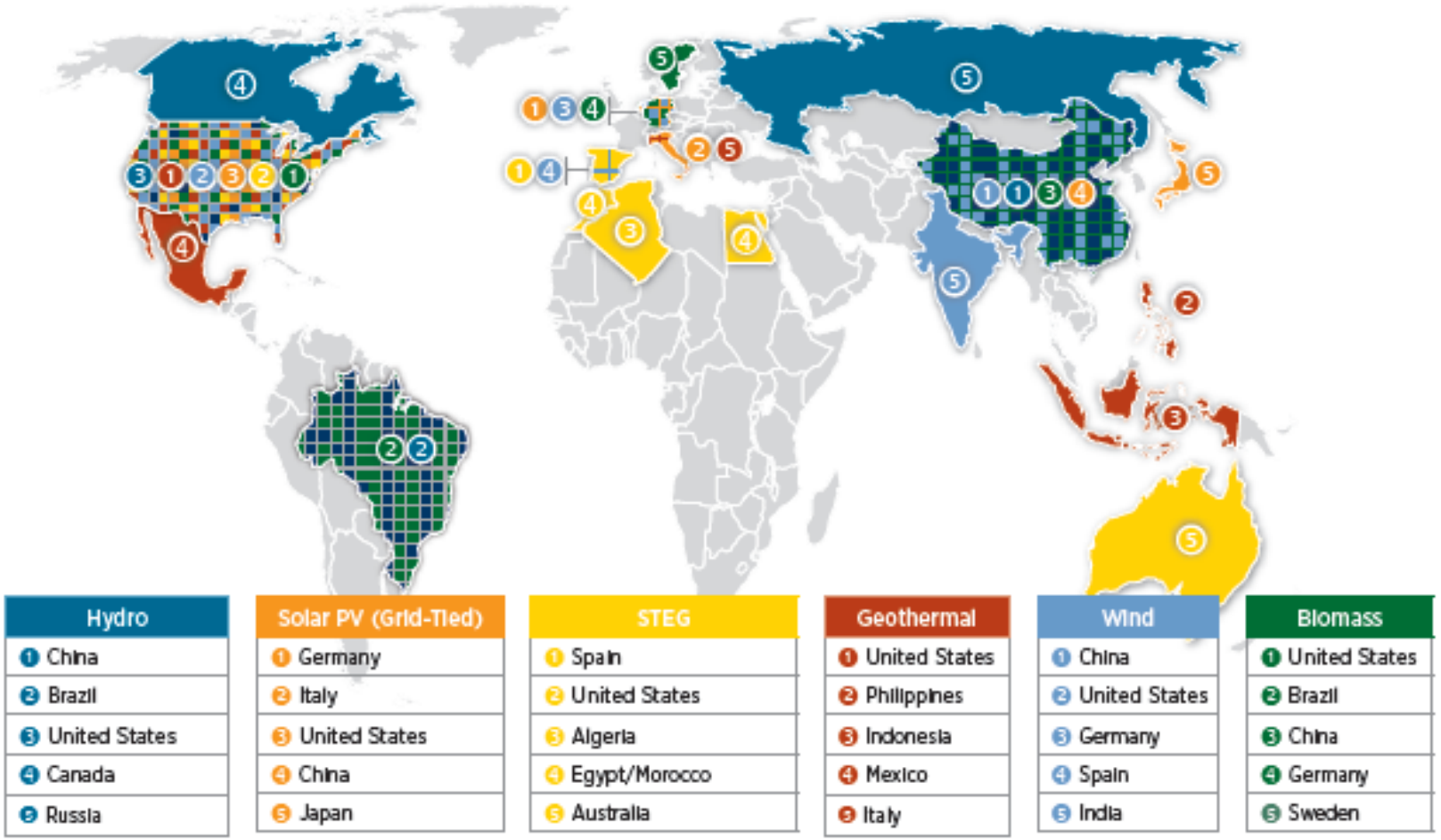
Note: Total values include estimates for undisclosed deals. Includes corporate and government R&D, and spending for digital energy and energy storage projects (not reported in quarterly statistics).

Source: Bloomberg New Energy Finance

Global Investment 2013



Top Countries with Installed Renewable Electricity by Technology—2012

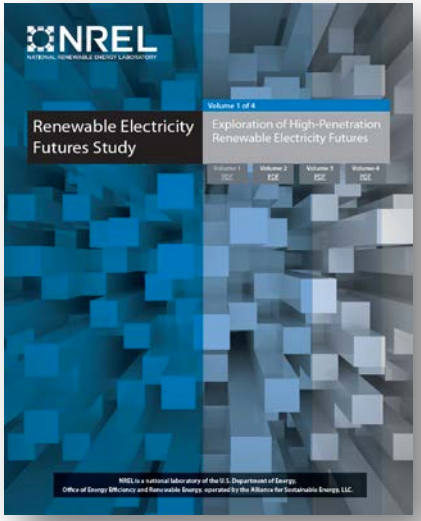


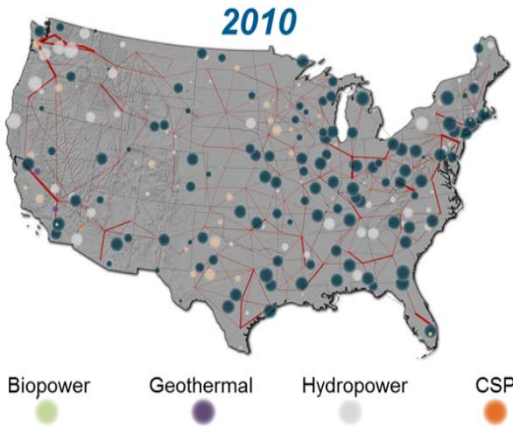
Hydro	Solar PV (Grid-Tied)	STEG	Geothermal	Wind	Biomass
1 China	1 Germany	1 Spain	1 United States	1 China	1 United States
2 Brazil	2 Italy	2 United States	2 Philippines	2 United States	2 Brazil
3 United States	3 United States	3 Algeria	3 Indonesia	3 Germany	3 China
4 Canada	4 China	4 Egypt/Morocco	4 Mexico	4 Spain	4 Germany
5 Russia	5 Japan	5 Australia	5 Italy	5 India	5 Sweden

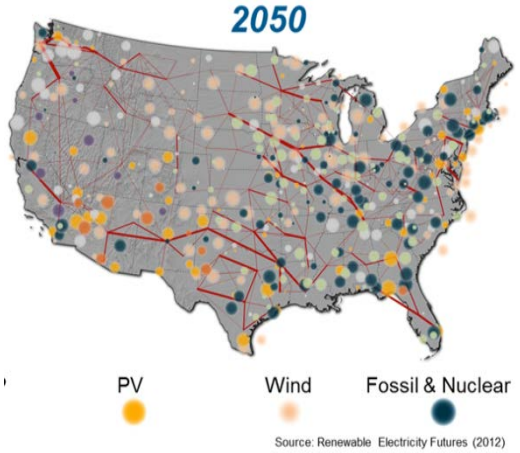
Sources: EIA, REN21

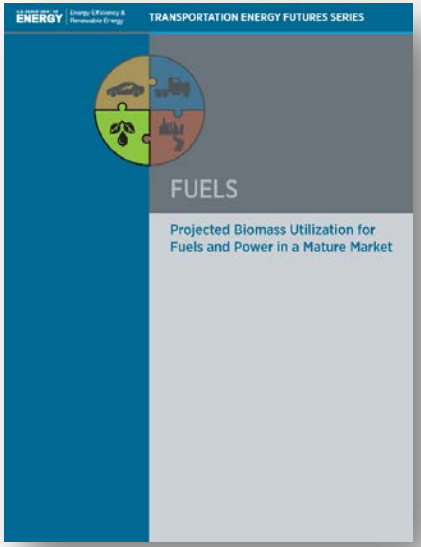
Source: NREL Data Book 2012

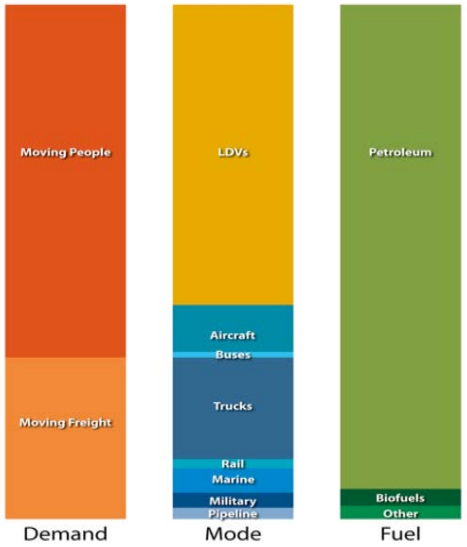
Comprehensive Studies Validate Opportunity for U.S. Renewables

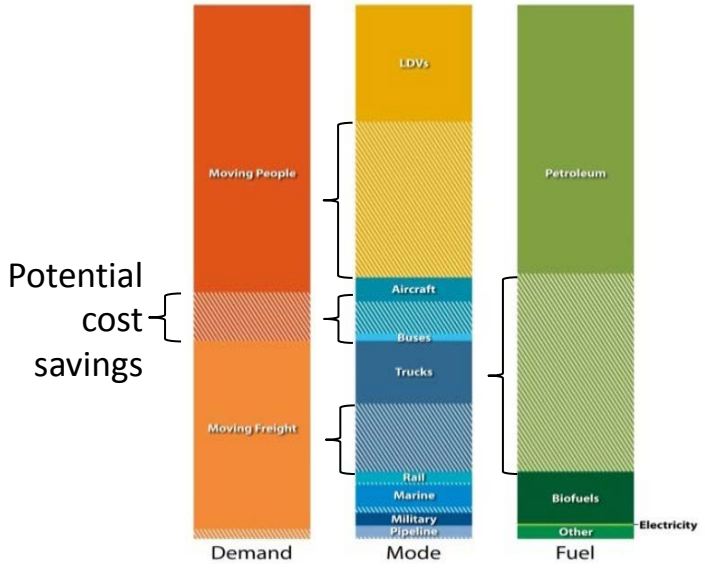




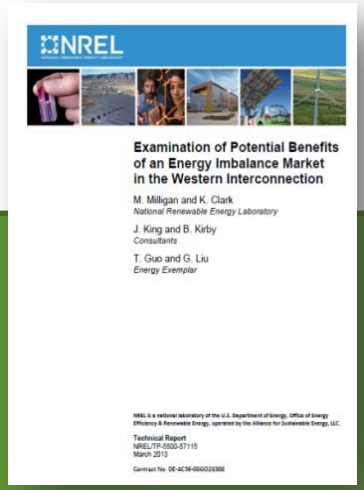


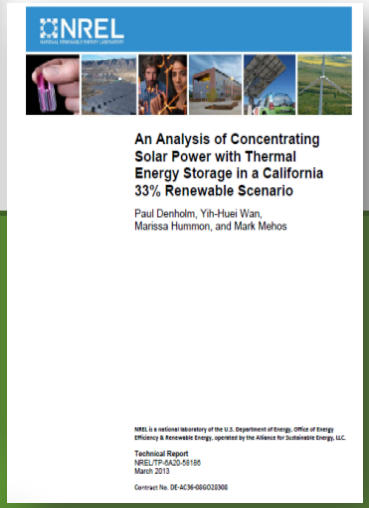


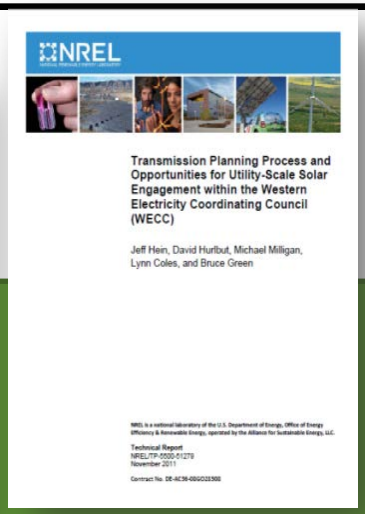


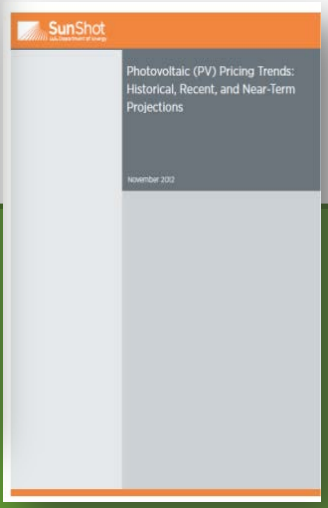


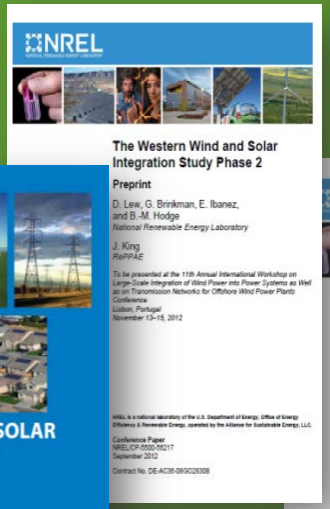
Looking Toward Implementation

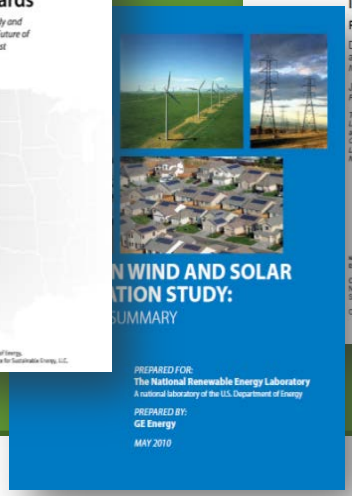


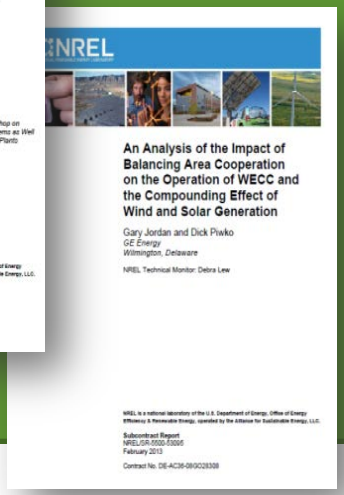












- Benefits of distributed generation
- Economics of technical pathways
- Implications of high penetration renewables
- Value of regional cooperation

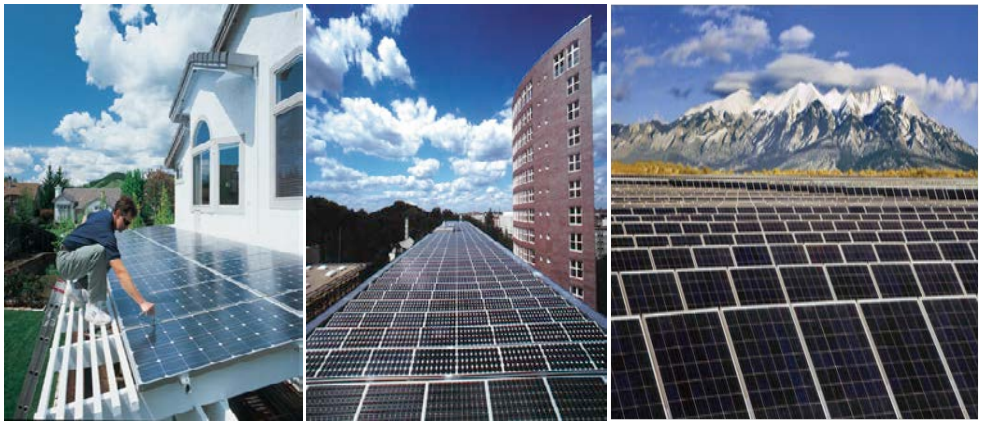
Technology Innovation

Sustainable
TRANSPORTATION

Renewable
ELECTRICITY GENERATION

Energy Saving
HOMES, BUILDINGS, & MANUFACTURING

Solar Electricity: *State of the Technology*



Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kWs to MWs to GWs
- U.S. Capacity: 12.1 GW
- U.S. Forecast: 40+ GWs in pipeline
- Costs: <$2 to $6/W: *LCOE 7 to 16¢/kWr
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

*With federal incentives, e.g., the FTC.

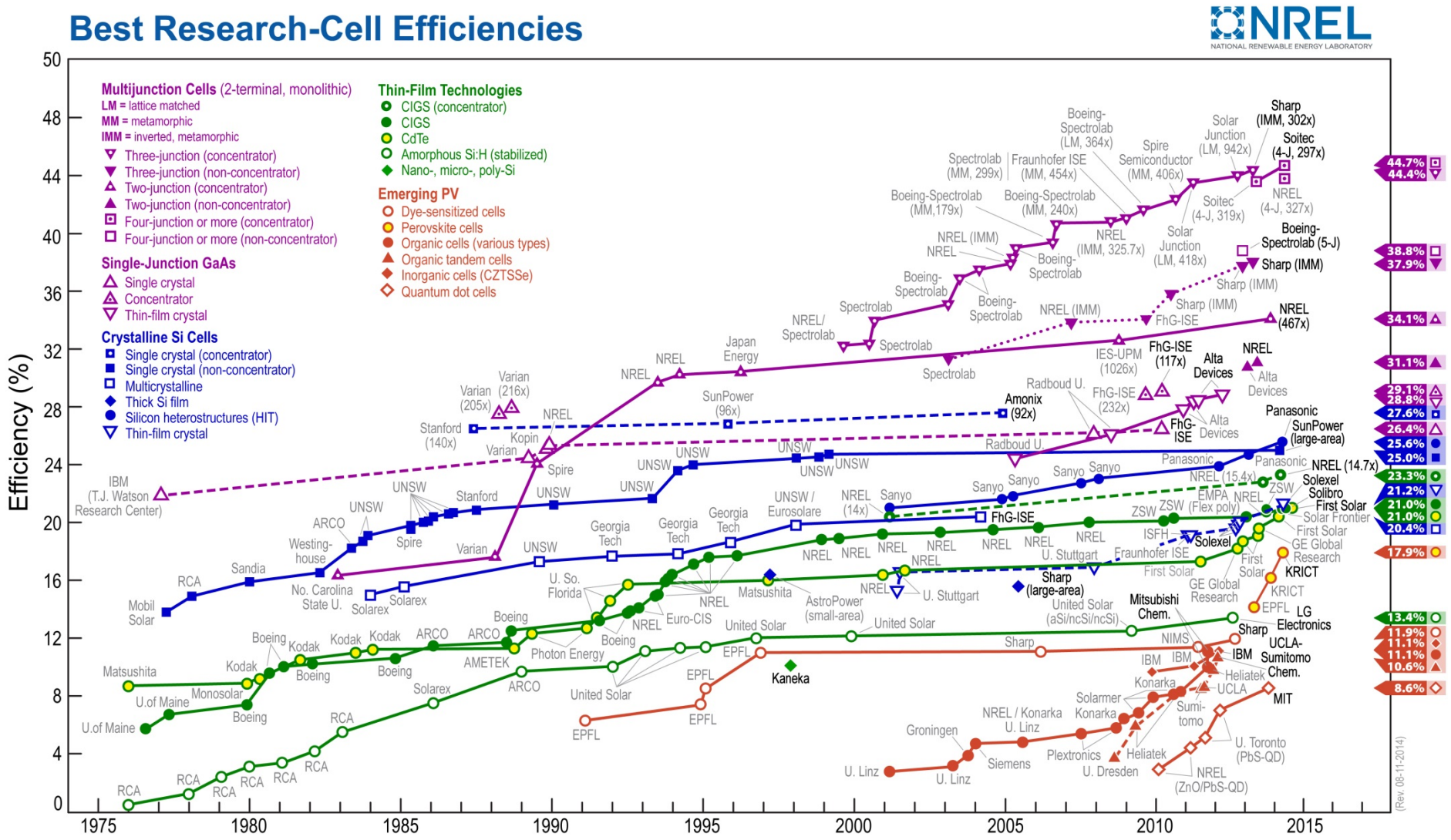
Solar Thermal Electric (CSP)

- Market: Commercial; Utility
- Geographically confined to “sun bowls”
- MWs to GWs
- U.S Capacity: 1186 MW at year end 2013, 672 MW installed in 2013, 640 MW under construction in 2014
- U.S. Forecast: 3.5 GWs in pipeline
- Costs: $4 to $8/W[†]: *LCOE 12 to 16¢/kWr
- Technologies: Conversion; parabolic troughs, central receivers, linear Fresnel, dish. Storage; thermal, up to 15 hours.

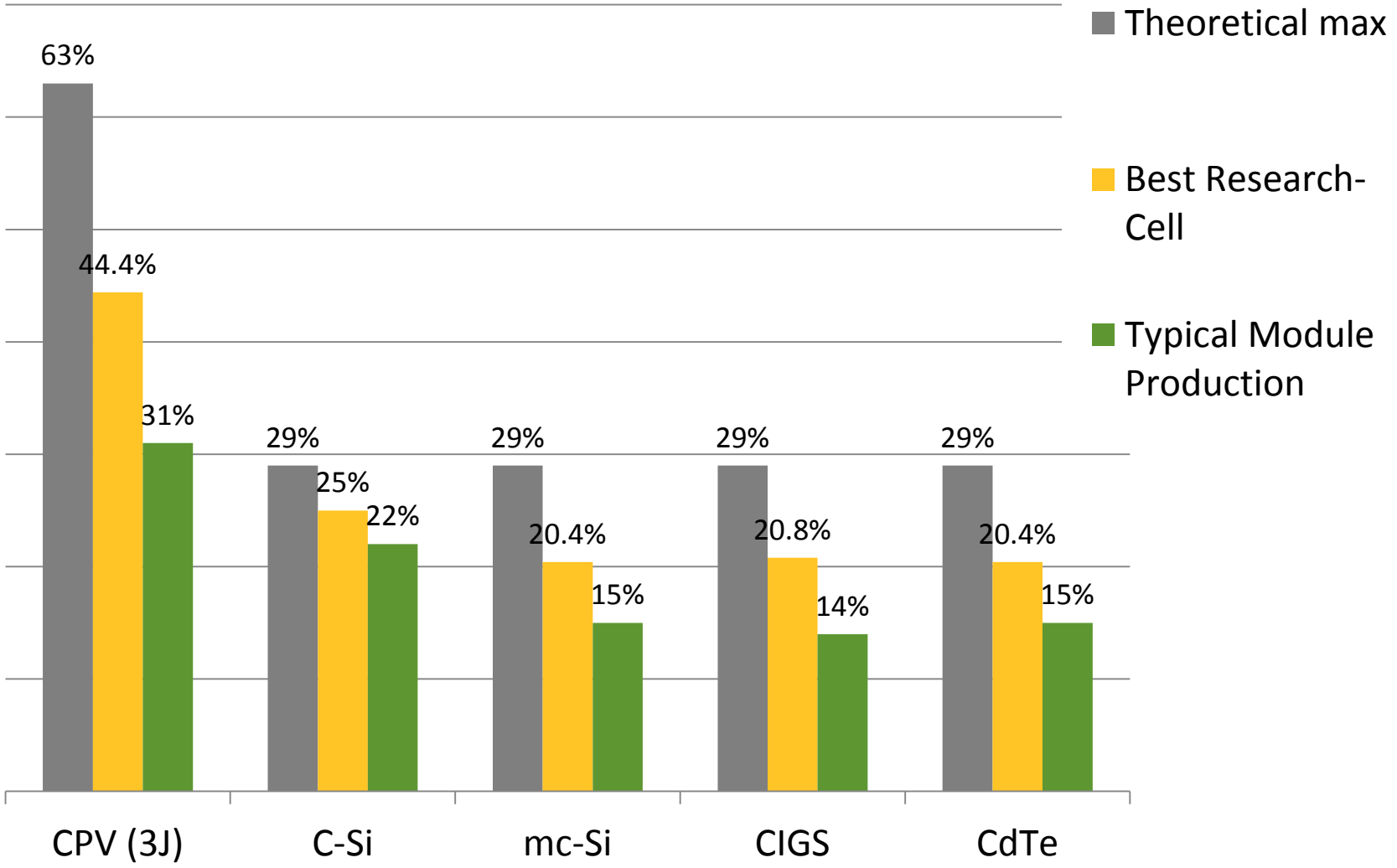
[†]Dependent on storage capacity

Updated: May 2014
Source: GTM/SEIA : U.S. Solar Market Insight 2011 - 2013 Year-in-Review

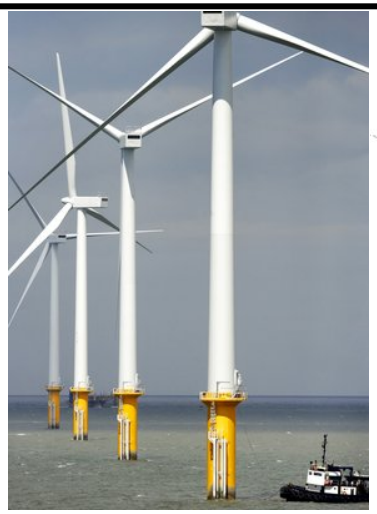
PV Research—Significant Innovation Space

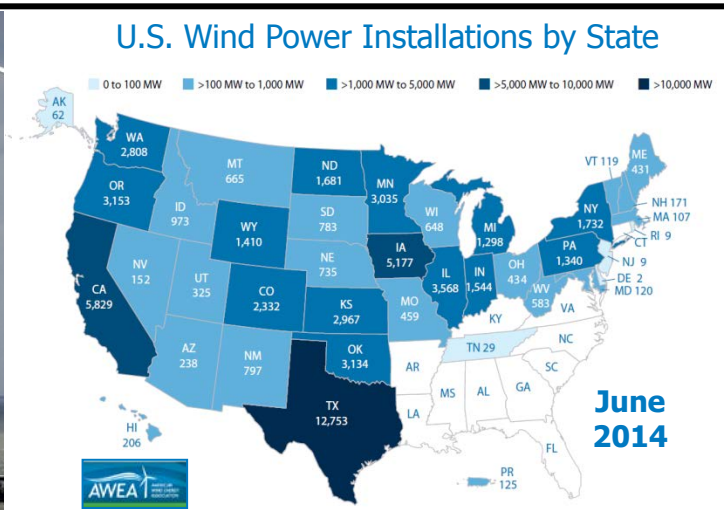


Commercial Performance Improving Rapidly



Wind Energy: *State of the Technology*





- Costs: 4-7 cents/kWh LCOE*
- Installed capital cost between $1,300 and $1,900/kW depending on region and size
- Commercial wind turbines rated at 1.5-3.0 MW in capacity are typical
- 7-10 MW wind turbines are in development and demonstration
- Variable speed and grid-friendly operation
- Advanced technologies are targeting low wind speed land based and deeper water offshore wind markets

- 61,946 MW of wind capacity installed in 39 states and Puerto Rico (June 2014)
- U.S. ranks 2nd in world for installed wind capacity equal to nearly 4.5% of total electrical demand
- Over 14,600 MW of wind under construction
- Price of wind for new contracts signed in 2013 at all-time low of 2.5 cents per kWh
- 560 wind manufacturing factories are spread across 43 states
- Wind business directly supported over 50,500 jobs
- Federal policy uncertainty is greatly impacting deployments between 2012 through 2014

* Estimate for utility-scale wind, class 4 wind sites, no subsidies

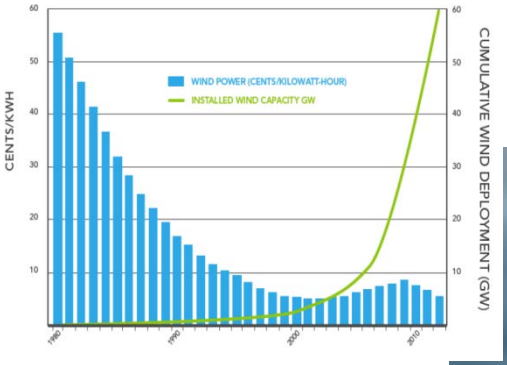
Updated: August 2014

Wind Technologies

ATMOSPHERE TO ELECTRONS
U.S. DEPARTMENT OF ENERGY

DOE Thrust: Atmosphere to Electrons

- Wind farm system improvements
- Component improvements
  - Modular large components – blades, drivetrains, and tall towers
  - Advanced drivetrain power conversion systems
  - Flexible, ultra-large rotors and systems
  - Active controls for structural load reduction, improved wind plant performance, and grid-friendly operation
  - Floating offshore wind turbines
  - Airborne wind power systems



Biofuels: *State of the Technology*

Current Status:

U.S. produced 13.3 billion gallons of ethanol and 1.34 billion gallons of biodiesel (2013)

Biorefineries:

- 211 commercial corn ethanol plants
- 115 biodiesel refineries
- 3 commercial cellulosic ethanol (1 operating, 2 scheduled to go online in 2014)

Cost goal:

Cellulosic ethanol—cost parity with gasoline was demonstrated by NREL/EERE at pilot scale in 2012

Major Technology Directions:

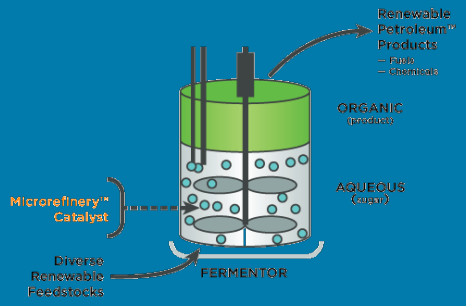
- Foundational Science: Enzymes, fermentation, understanding biomass and cell wall composition, deoxygenation catalysts
- Feedstocks: Sustainable feedstock production systems
- Biofuels Conversion R&D: Biochemical and thermochemical conversion processes to hydrocarbon fuels
- Advanced Biofuels and Algae: Broadening RD&D to address cost competitive production of "drop in" high-energy content fuels from biomass and algae

Updated 3/2014

Biofuels

New conversion technologies are being developed, offering the possibility of revolutionary, high volume methods for producing biofuel hydrocarbon fuels for our trucks, trains, ships, and aircraft

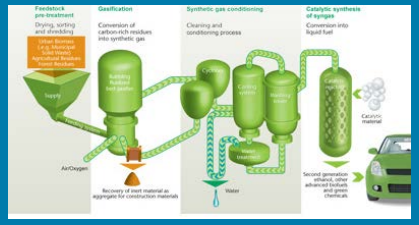
Biological Conversion



LS9

AMYRIS

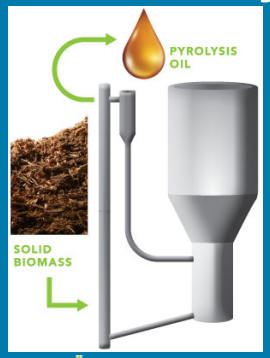
Chemical Catalytic Conversion



VIRENT
IT'S ABOUT TIME

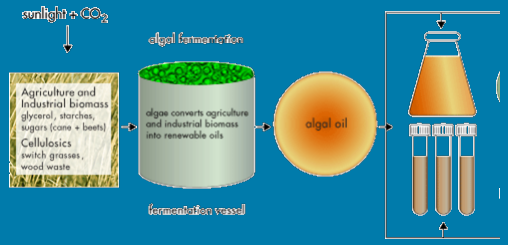
Enerkem

Pyrolysis/Bio-Oil Pathways



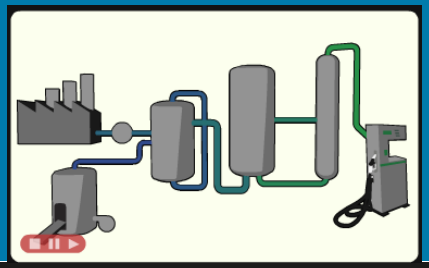
Envergent
TECHNOLOGIES
A Honeywell Company

Heterotrophic Algae Conversion



solazyme®

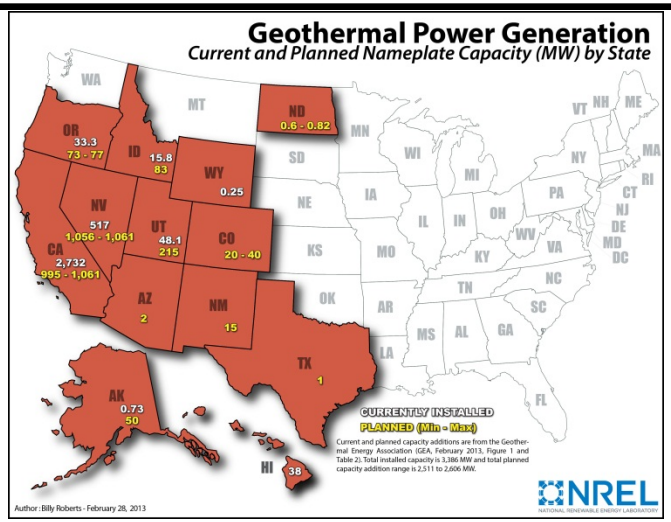
Hybrid Conversion Technologies



LanzaTech

coskata

Geothermal Energy: *State of the Technology*



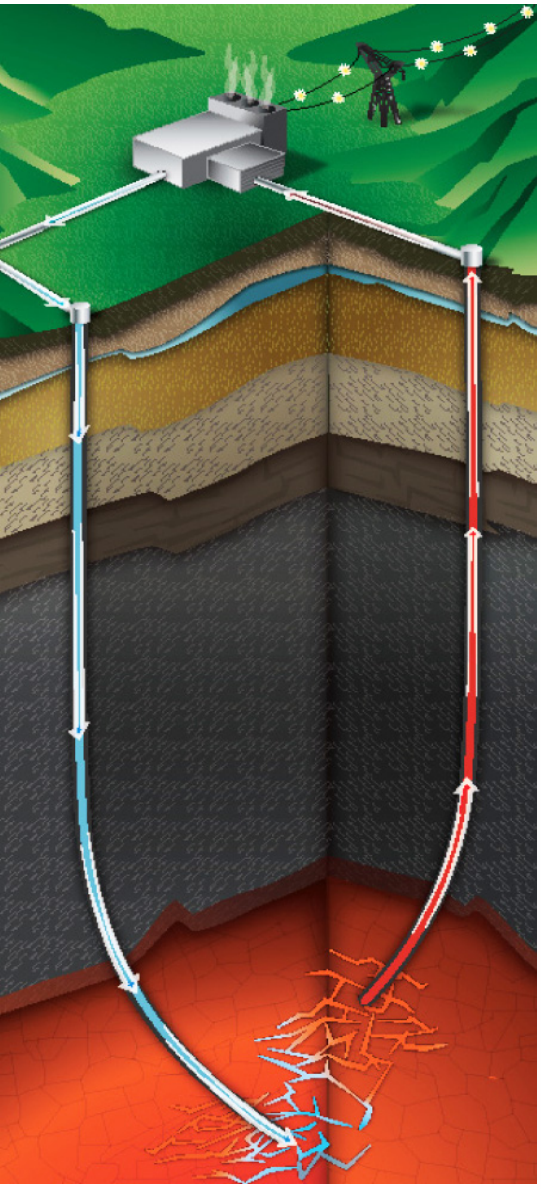
- Costs: 6-10 cents/kWh LCOE*
- Installed capital cost = $3,000-$5,000/kW
- Binary geothermal power plants typically 10-30 MW in size
- Flash and steam power plants typically 30-100 MW in size
- Distributed generation options becoming available at 30 kW and above
- Baseload generation with high availability

- Worldwide installed capacity: 11,224 MW (2012)
- U.S. installed capacity: 3,187 MW (4/2013), the largest in world
- Installed US geothermal power capacity grew 5% in 2012, 147 MW in new capacity added and 175 additional projects under development
- 8 states with installed geothermal capacity, and 5 more states with projects under development
- “Enhanced Geothermal Systems (EGS)” demonstration projects marking significant achievements, including first US commercial, grid-connected EGS system

* Based on recent PPA prices in US

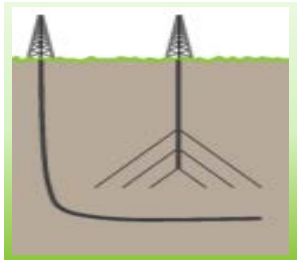
Updated: March 2014

Enhanced Geothermal Systems



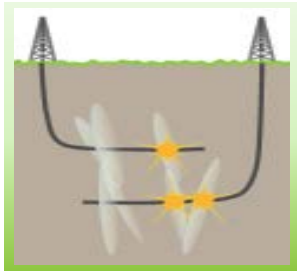
WHY?

- **Promote transformative science and engineering to:**
  - Address key barriers
  - Validate and optimize EGS technology
  - Capture high fidelity data
  - Ensure deep understanding and reproducibility for commercial scale-up
- **Federal Role:**
  - Test technologies/take technical risks not possible in private sector
  - Work under aggressive timeframe
  - Gather and disseminate comprehensive data sets
- **Direct benefits to all areas of research in the geothermal space**



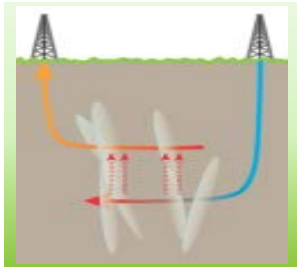
Reservoir Access

New well geometries and concepts, optimized drilling



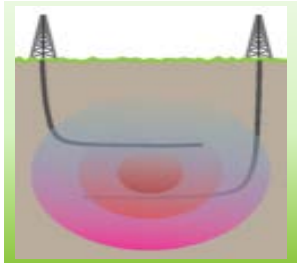
Reservoir Creation

Characterize local stress, zonal isolation, novel fracturing methods, increase fractured volume per well



Productivity

Increase flow rates without excessive pressure needs or flow localization



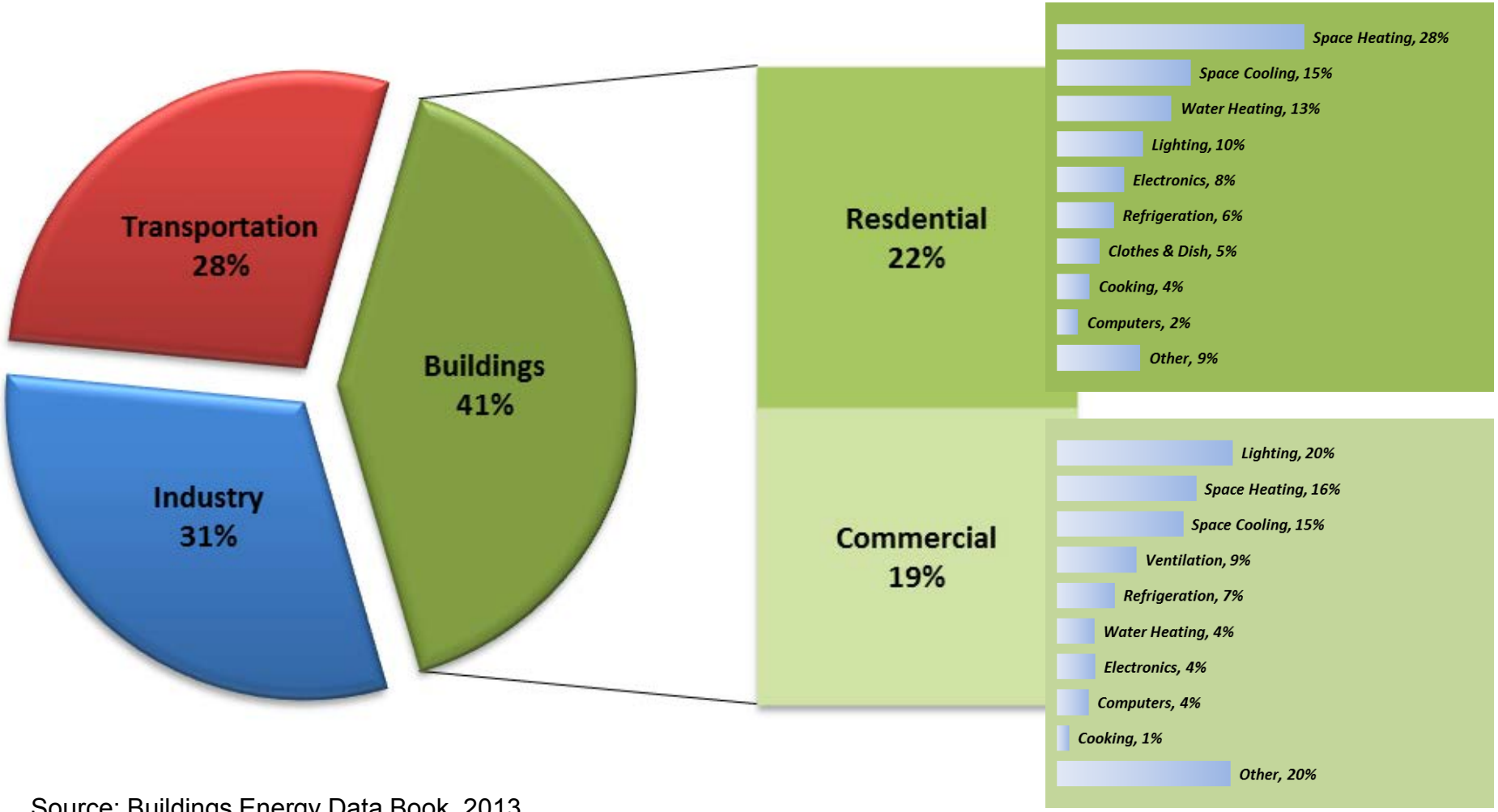
Sustainability

Maintain productivity with minimal thermal drawdown and water losses

Energy Efficiency

- ***Buildings*** **(40%) – envelope design, daylighting, better lights, efficiency standards**
- ***Transportation*** **(30%) – lighter weight vehicles, public transportation, PHEVs**
- ***Industry*** **(30%) – heat recovery, better motors, CHP**

Energy Consumption in the U.S.



Source: Buildings Energy Data Book, 2013

Buildings Technologies

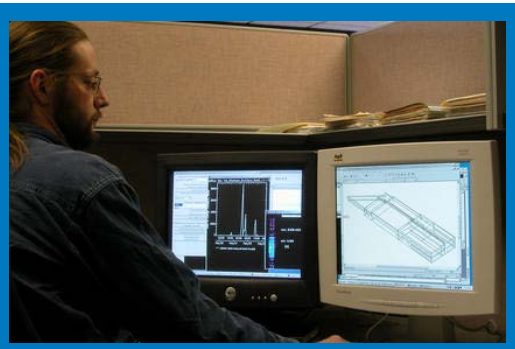
High Performance Buildings

BIPV Products and PV-T Array

Compressorless Cooling

Electrochromic Windows

Automated Home Energy Management



Computerized Optimization and Simulation Tools

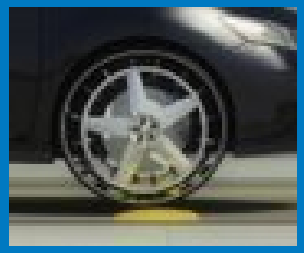
Transportation Technology Thrusts

Portfolio of technologies leading to 54.5 mpg

Degree of electrification (power electronics and energy storage)

Start/stop

Regenerative braking



Low rolling resistance tires

Electric infrastructure

Electric powered steering

Light weighting

8 speed transmissions

Turbocharging, direct fuel injection, advanced combustion

Variable cylinder mgmt

Improved aerodynamics

Diesel powered and or Alternative Fuels, H2

Sustainable Transportation

EV Everywhere Grand Challenge

EV Everywhere Blueprint (Jan 2013)

Reducing PEV costs and breaking down the most difficult PEV *EV Everywhere* deployment barriers.

Bioenergy Technologies

(Dollars in Thousands)	FY 2013 Current	FY 2014 Enacted	FY 2015 Request
Feedstocks	47,359	46,972	30,500
Conversion Technologies	75,140	101,384	100,500
Demonstration and Deployment (formerly Integrated Biorefineries)	43,630	64,790	105,000
Strategic Analysis and Cross-Cutting Sustainability	14,939	12,146	11,000
Biopower/Cookstoves	4,122	1,998	0
NREL Site-Wide Facility Support	0	5,000	6,200
Total, Bioenergy Technologies	**185,190**	**232,290**	**253,200**

Vehicle Technologies Battery R&D

FY 2015 Goal: Reduce the cost of a PHEV40 battery to $275/kWh

Fuel Cell Technologies

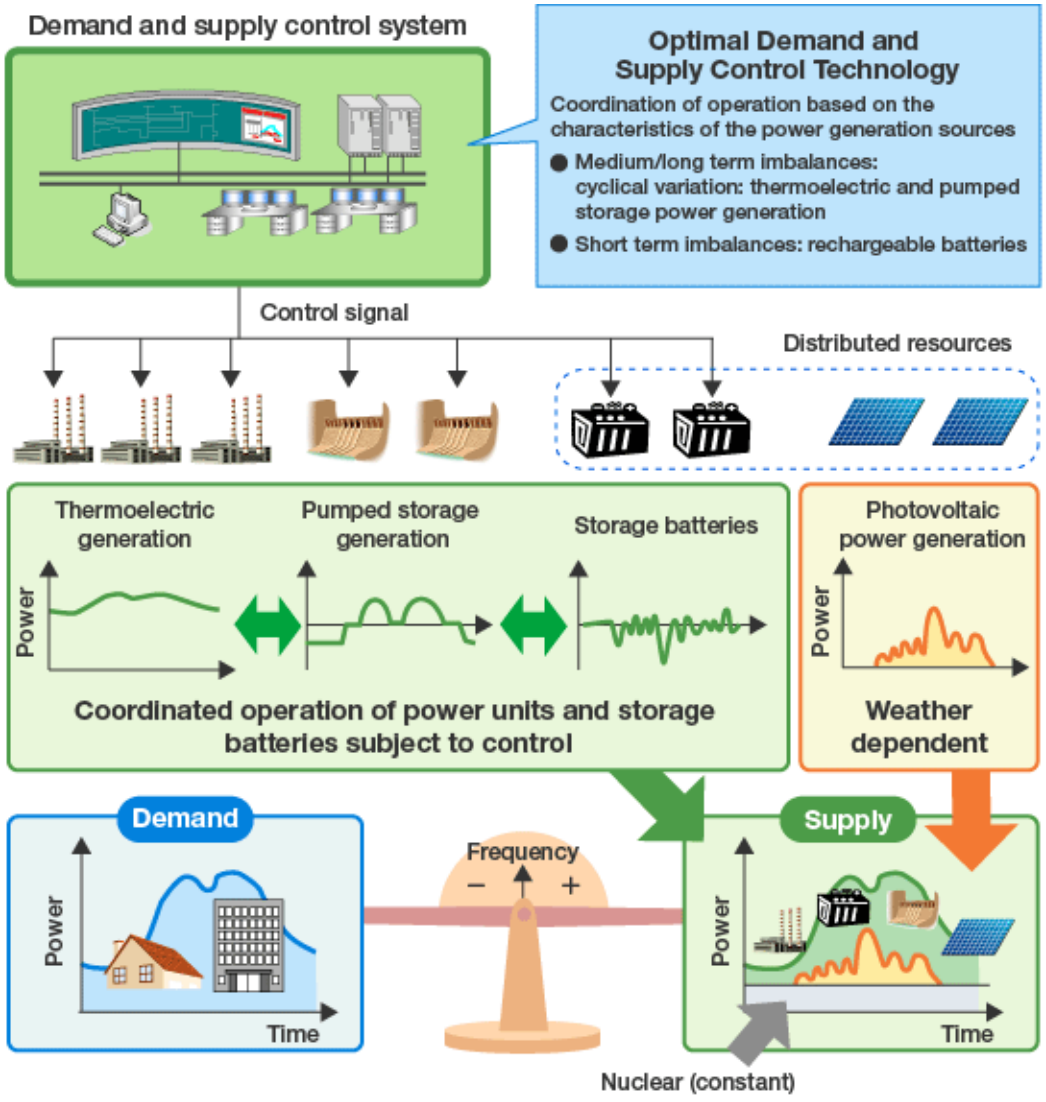
(Dollars in Thousands)	FY 2013 Current	FY 2014 Enacted	FY 2015 Request
Fuel Cell R&D	41,266	33,383	33,000
Hydrogen Fuel R&D	31,681	36,545	36,283
Manufacturing R&D	1,899	3,000	3,000
Systems Analysis	2,838	3,000	3,000
Technology Validation	8,514	6,000	6,000
Safety, Codes and Standards	6,808	7,000	7,000
Market Transformation	2,838	3,000	3,000
NREL Site-Wide Facility Support	0	1,000	1,700
Total, Fuel Cell Technologies	**95,844**	**92,928**	**92,983**

The New Frontiers: Integration and Scale

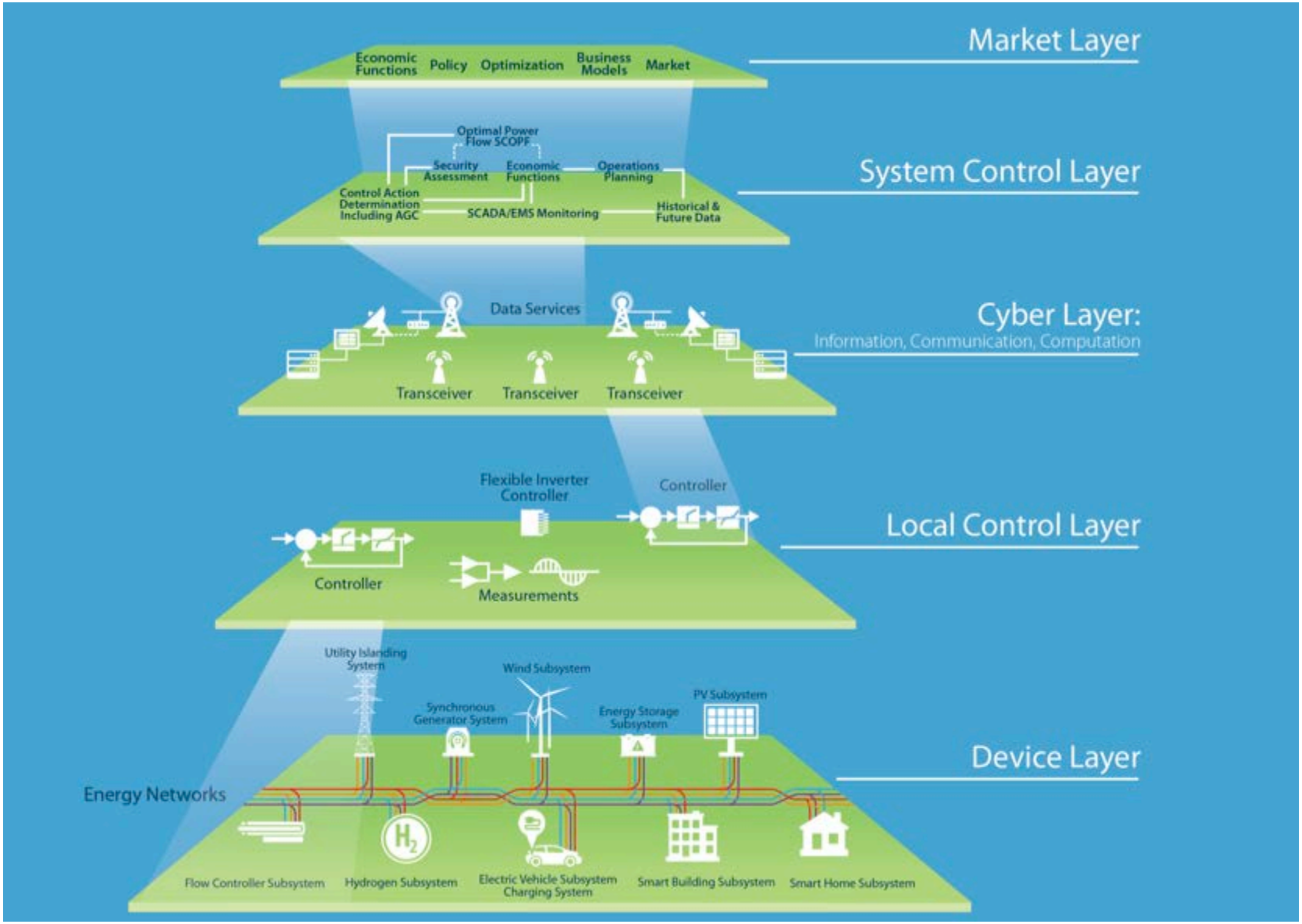
- Integration of high-penetration renewables requires enhanced system-wide flexibility
  - Variable supply and variable load
  - Increased distributed resources
  - Enhanced energy imbalance market cooperation
  - Changing roles of consumers, utilities, investors, power providers, vendors, and regulators
- Regional considerations continue to drive progress
- Production scale and supply chain crucial to lower manufacturing costs
- Investment in technology R&D imperative
  - Better monitoring and measurements
  - Advanced analytics processing and control
  - Demand-shifting and load profile shaping techniques
  - Two way power flow control electronics

Grid Integration Issues

- High wind and solar penetration means lesser but ***more variable*** use of other assets
- Issues with voltage regulation, protection and coordination can limit PV
- High efficiency, demand response, and new loads are changing demand and making it ***more variable***
- Existing T&D grid increasingly strained by two-way power flow



Integrate Across Functional Layers



Innovation, Integration and Adoption

Reducing Investment Risk

- Enable basic and applied clean energy technology innovation
- Accelerate technology market introduction and adoption
- Integrate technology at scale
- Encourage collaboration in unique research and testing "partnering" facilities

Mobilizing Capital

NREL Supports Both Installation and Operational Energy Missions

	Installation	Operational
Fuel	Non-tactical Vehicles Only	Primary Energy Source
Electricity	Dependence on National Grid	Diesel Generation, Soldier Electronic Systems and Batteries
Approach	• Smart microgrids • Renewable integration and storage • Enterprise-level management • Replicable, modular process and systems • Load reduction and management • Vehicle electrification and grid integration	• Demand-side management • Energy Efficiency • Hybrid diesel/renewable generation systems • Microgrid design and implementation • Logistics optimization • Battery/renewable hybrid soldier electronic systems • Renewable generation (e.g., waste to energy, PV)

Fixed Installation

Training

Force Projection

Forward Operating Base

DoD Installation Energy – Relevant Examples

- **Energy Assessments**
  - All Army, Navy, and Marine installations worldwide (desktop)
  - Engaged in “boots on the ground” follow-up
  - Rich data source for analysis and decision support
- **Navy HI/Guam Energy Improvement Projects**
  - Near-commercial demonstrations at Navy installations
  - Includes generation, efficiency, and energy systems integration
- **Microgrid Design and Implementation Support**
  - Projects for Air Force, Marines, Army and Navy
  - Providing energy security and cost savings
- **Strategic Advisor**
  - Army Energy Initiatives Task Force
  - IPA with Energy Security Technology Certification Program
  - Support to OSD DUSD for Installations, Energy and Environment

DoD Operational Energy – Relevant Examples

- **Operational Energy**
  - *Energy Efficient Outpost Modeling Consortium (EEOMC).* Four year project with Office of Naval Research to model and monitor FOBs/COPs. Funded by Operational Energy Plans and Programs (OEPP). NPS is part of the team
  - Held 2013 joint Energy-to-the-Edge workshop with Army Rapid Equipping (REF).
  - Developing consolidated Utility Base Energy (CUBE) microgrid system for Army
  - Energy evaluations at Bagram Air Base, Afghanistan and Soto Cano, Honduras. Joint project with Sandia in support of OEPP
  - FOB structure modeling for USMC and Army to optimize efficiency

Reduced Costs, Energy Security, Operational Excellence

Technology Validation

NAVFAC Hawaii-Guam Demos

ESTCP Demos

Energy Systems Integration Facility

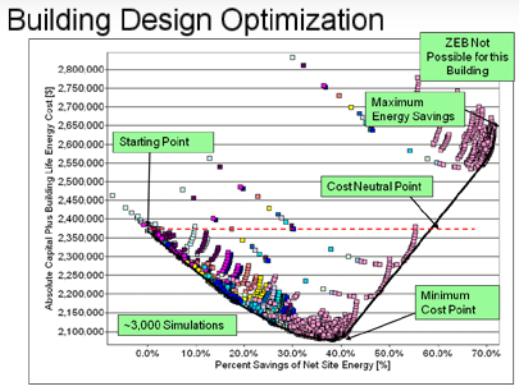
Alternative Fuel Vehicles

Strategic Advisor

Technical Input to Energy Strategies

Installation Energy Assessments

Techno-economic analysis



Innovation

Highly Efficient Building Technologies

Portable Hybrid Power Systems

Drop-In Biofuels

Advanced Solar Techs

Energy Project Assistance

Project Development

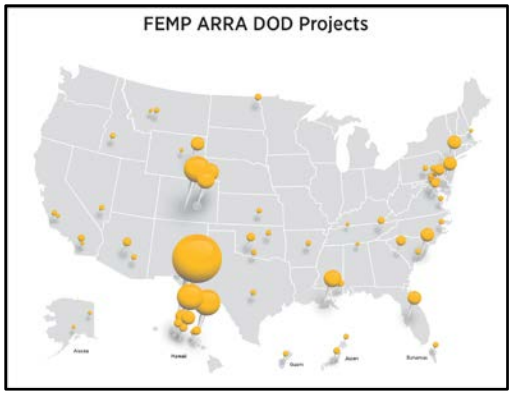
Net Zero Projects

Utility Scale RE

EE Strategies

Microgrids

Project Financing Support



Energy Systems Integration Facility

A Risk-Reduction Asset for DoD

- Shakedown testing
- System and component evaluations
- Operational and Installation scales
- Test hardware at scale with real-time feedback from operational systems (Hardware in the Loop)
- Modeling and simulation of complex, dynamic energy systems
- Test components and systems under variable/extreme conditions

http://www.nrel.gov/esi/esif.html

Test limits at the ESIF, not in the field!

To achieve a clean energy vision, we must…

Invest in innovation

Invent the future we desire

Improve access to capital

Partner on a global scale

NREL

NATIONAL RENEWABLE ENERGY LABORATORY